Journal of Thermal Biology 81 (2019) 128–136

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

The dynamic adaptation of Brazilian Brahman bulls

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ARTICLE INFO

Keywords:
Beef cattle
Bos indicus
Multivariate analysis
Seasons
Thyroid
Tropical conditions

ABSTRACT

Heat stress is one of the most important factors that affect the performance of some *Bos taurus* breeds and crosses in tropical regions. The Brahman breed was developed in hot regions of the world and often has genes that confer resistance to heat stress compared to other breeds of beef cattle. The goal of this work was to evaluate the adaptive responses of Brahman bulls, based on physiological, hormonal and hair characteristics according to season. The physiological, hormonal and hair characteristics were rectal temperature (R_T), respiratory rate (R_R), sweating rate (S_R), triiodothyronine (T_3), thyroxine (T_4), cortisol concentrations (C_O), coat thickness (C_T), hair length (H_L), hair diameter (H_D) and hair density (N_D). These were recorded in Brahman bulls from a Cerrado biome during four seasons: spring (21 September to 20 December), summer (21 December to 17 March), autumn (18 March to 20 June) and winter (21 June to 20 September). Data was analyzed using a general linear model that included season as a fixed effect; in addition, multivariate tests and logistic regression were also used to characterize the animals within each season. The meteorological variables defined the four seasons, besides identifying climatic differences between them. Significant differences ($P > 0.05$) were found for most of the physiological, hormonal and hair characteristics according to season. The Brahman bulls presented particular adaptive characteristics in each season. Individually, most of the Brahman bulls presented the same adaptive reaction in each season; particular similarity occurred for the summer and autumn. This pattern is a reflection of the inter-relationships between physiological responses and hair characteristics.

1. Introduction

Environmental high temperatures are detrimental to the productivity of the livestock industry because animals of genotypic desired characteristics for beef production normally have higher endogenous heat due to their metabolic activity. Heat stress (HS) is one of the most important factors that affect the performance of some *Bos taurus* breeds and their crosses in tropical regions, especially when they are managed in extensive conditions (Silanikove, 2000; McManus et al., 2011). In Brazil, the search for heat tolerant genotypes has increased over the years because of their ability to adjust to climatic changes (Urbano et al., 2015). The *Bos indicus* cattle are particularly adapted to hot climates and possess superior ability to regulate body temperature (Hansen, 2004). According to Dikmen et al. (2018), the Brahman breed were developed in hot regions of the world and often have genes that confer resistance to HS, compared to Angus and Hereford breeds of beef cattle.

Individual susceptibility to HS is influenced by many factors, including its species, fat score, skin and coat color, temperament, sex, and skin thickness (Scholtz et al., 2013). The capacity of the animals to maintain equilibrium with the thermal environment is directly associated with their ability to trigger thermoregulatory mechanisms. This depends on a pool of morphological, physiological and hormonal traits acquired during the evolutionary process, in order to guarantee the efficiency of thermoregulation (Façanha et al., 2016).

Brahman cattle have strong skin pigmentation which filters the intense shortwave radiation as well as keeping the breed free of cancer. A special feature of the Brahman breed is their ability over other breeds to sweat freely, which contributes greatly to their heat tolerance, as found in the research by Silva et al. (2017). Other adaptive advantages that

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https://doi.org/10.1016/j.jtherbio.2019.02.016
Received 14 July 2018; Received in revised form 29 September 2018; Accepted 24 February 2019
Available online 25 February 2019
0306-4565/

make the Brahman well suited to many environmental conditions include the ability to consume lower-quality food, to walk longer distances for feed and water, to be resistant to internal and external parasites and the ability to reproduce on a regular basis in a stressful environment (Hoffmann, 2010; Mu et al., 2013). A factor which contributes to the Brahman's unique ability to withstand extreme temperature is a short, thick, glossy coat, which reflects much of the sun rays, allowing them to graze in midday sun without suffering.

The goal of this work was to evaluate the adaptive responses of Brahman bulls, based on physiological, hormonal and hair characteristics according to season. The hypothesis is that there is a specific adaptive trait profile for each season.

2. Material and methods

The study was performed in a commercial farm located in Uberlândia city in Minas Gerais state, Brazil, at 18°55′S, in the Cerrado biome. Sixty-three Brahman bulls were used, whose initial age ranged from 233 to 264 days and initial body weight (B_W) was 193.5 ± 54 kg.

The physiological, hormonal and coat variables were collected from spring to winter, marked by the following dates: spring (21 September to 20 December), summer (21 December to 17 March), autumn (18 March to 20 June) and winter (21 June to 20 September). In these periods, samples were taken between 8:00 a.m. and 11:00 a.m. once a month for two months except for winter, under natural field conditions.

The climatic variables registered consisted of air temperature (A_T, °C), relative humidity (R_H, %) – both measured with a portable digital thermohygrometer positioned above the animals –, wind speed (W_S, m s^{-1}) – was measured with a digital anemometer – and as an animal thermal comfort indicator the radiant heat load (RHL, W m^{-2}), calculated using the formula of Esmay (1969). These variables were registered at the same time of data collection in the animals in each month corresponding to the season.

The animals in this study were raised in an extensive system and accustomed to daily management (weighing, vaccination and destaining) from birth, therefore, during this experimental period, the animals accustomed to handling and recording procedure to reduce their stressful impact. The weighing was carried out in electronic scales and physiological responses assessed included rectal temperature (R_T, °C), which was measured with a digital thermometer (Omron Flex Temp Digital Thermometer, China); respiratory rate (R_R, breaths min^{-1}), which was recorded by counting the number of flank movements for 1 min; and sweating rate (S_R, g m^{-2} h^{-1}) was estimated using the colorimetric method of Schleger and Turner (1965). However, to improve the precision of the measurements, we used the device developed by Pereira et al. (2010), which was built from two transparent acrylic plastic plates and provided better adhesion of the paper discs to the skin and so that lateral slide movements were minimized. Higher precision and lower repeatability of S_R measurements were achieved using the approach described above. This approach is also advantageous in that several animals can be measured simultaneously. In addition, measurements can be made a variety of times in large-scale studies where animals are kept under field conditions. In cattle, the sacral area can be used for sampling because this part of the body does not interfere with their social interactions with other animals. Blood samples were collected from jugular vein into vacuum tubes without anticoagulant, centrifuged at 3000 rpm for 5 min and frozen at −20 °C. Hormonal serum concentrations of triiodothyronine (T_3, ng mL), thyroxine (T_4, µg dL) and cortisol concentrations (C_O, µg dL) were determined using commercial kits in an automatic Elisa device (Elysis Uno®, Human®) validated for bovine samples.

Examined hair coat traits included coat thickness (C_T, mm) determined in situ in the middle of the thorax of each animal about 20 cm below the dorsal line with a thin metal rule. Hair samples were taken from the same region where C_T was measured and were removed using pliers (Silva, 2008). The sample hair was removed, stored in plastic envelopes and the measurements of hair length (H_L, mm), hair diameter (H_D, µm) and hair density (N_D, hair cm^{-2}) were recorded in the laboratory.

The N_D was obtained by counting the number of hairs removed in 0.1399 cm^2 using pliers according to Lee (1953) and then converted into 1 cm^2 (Maia et al., 2003). H_L was taken as the average length of the 10 longest hairs in the sample, according to Udo's method (1978). The number of hairs per unit area (hair cm^{-2}) was obtained by direct counting of all hairs in the sample. A digital micrometer, Mitutoyo model, with scale 0–25 µm was used to measure mean H_D; the hairs were the same used for the measurement of H_L. The average H_D was also based on measurements of the 10 longest hairs in the sample.

Data was analyzed using a general linear model, which included the months (September, December, January, February, March, April and June) or season (spring, summer, autumn and winter) as fixed effects, and a mean test was used (Tukey's test). Pearson correlations were also tested between variables studied.

After standardization, multivariate analyses were carried to allocate animals in groups according to similarity and to verify the discriminatory capacity of the original variables. The principal component analysis allowed assessment of overall variance; on the other hand, discriminant analysis describes the variation among groups and identifies variables with greater discriminatory power between animals. Relative importance was assessed by eigenvalues (variances), thereby defining the factors to be extracted by the method of *varimax* rotation for better interpretability groups formed. A logistic regression analysis calculation was carried out to identify which seasons are more to HS considering the physiological responses and hormonal examinations, as well as in the work of Cardoso et al. (2015) and Dalcin et al. (2016).

This experiment was approved by the Ethics Committee of the Federal University of Semiarid (UFERSA; process number: 23091003895/2014-71).

3. Results

Air temperature (A_T) presented variation close to 5.4 °C between seasons, ranging from 22.8 ± 2.7 °C to 28.2 ± 2.5 °C in the winter and summer seasons with significant difference ($P < 0.05$), respectively (Fig. 1). In addition, minimum and maximum relative humidities (R_U) were observed between 44.0 ± 2.1% (spring) and 71.2 ± 5.6% (autumn) with significant difference between seasons ($P < 0.05$). In these circumstances, minimum and maximum wind speed (W_S) ranged from 0.4 ± 0.8 m s^{-2} (autumn) to 4.9 ± 3.2 m s^{-2} (summer). All variables differed significantly ($P < 0.05$) between seasons, where the combined between highest values of A_T, R_U and the values of W_S of seasons caused an increase in the radiant heat load (RHL), especially in spring differing significantly from all other averages, followed by summer, autumn and winter.

The mean B_W showed a significant difference ($P < 0.05$) between seasons (Table 1), since the animals were in a promising phase for body growth, so during the study period the Brazilian Brahman bulls gained about 120 kg, with an average daily gain of B_W of 0.740 g per day.

For rectal temperature (R_T), respiratory rate (R_R) and sweating rate (S_R) of Brahman bulls, there was a significant difference between seasons ($P < 0.05$; Fig. 2): the R_T presented variation close to 1 °C between seasons, whereas spring and summer as well autumn and winter were similar and non-significant. The results found for the respiratory rate (R_R) and sweating rate (S_R) did not follow the same pattern. Although the animals showed different SR values between seasons, especially in the winter season ($P < 0.05$); in other words, for both the minimum respiratory pattern in summer and the maximum in autumn, animals presented the same SR.

Among the hormonal responses, triiodothyronine (T_3) was the only one that did not show a significant difference between seasons (Fig. 2). Thyroxine (T_4) had high values in spring and summer and a significant difference ($P < 0.05$) between other seasons. The largest serum

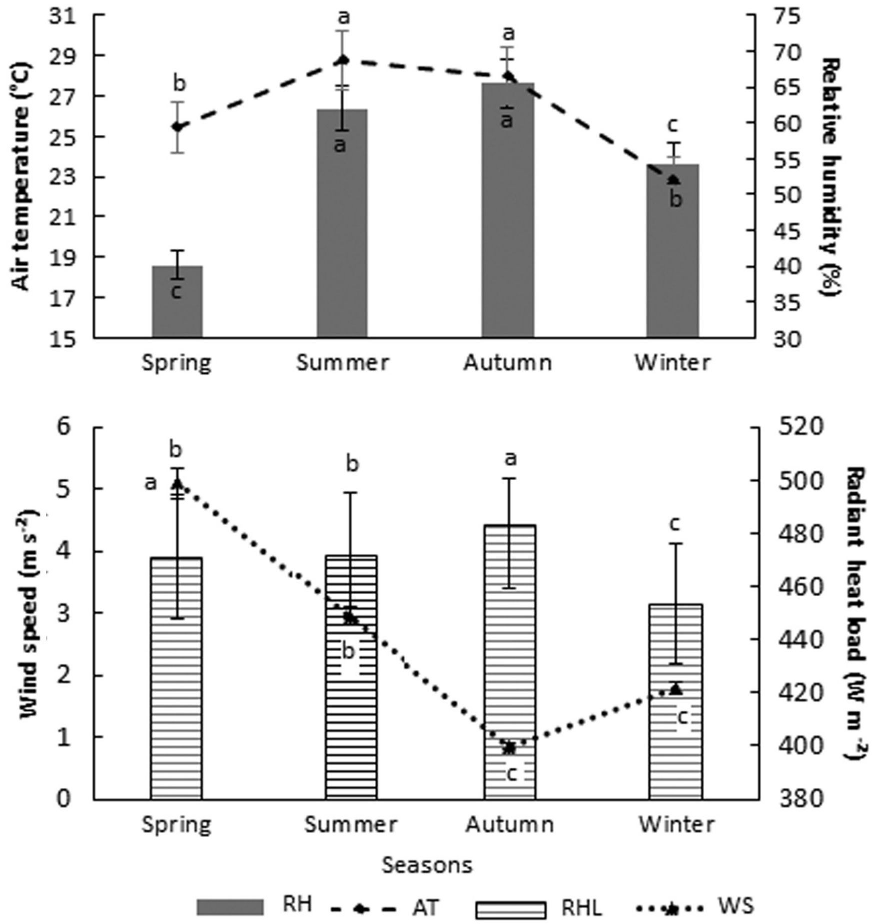

Fig. 1. Climatic variables and animal thermal comfort indicator measured in the different seasons during the study

Table 1
Body weight (B_W) of Brazilian Brahman bulls in Cerrado biome during different seasons (Results are mean ± Standard deviation, n = 63).

Variable	Seasons				CV (%)
	Spring	Summer	Autumn	Winter	
B_W (kg)	$223.95^a \pm 6.64$	$270.50^b \pm 6.64$	$302.36^c \pm 6.64$	$345.68^d \pm 6.64$	10.58

Different letters indicate significant difference (P < 0.05).

concentrations of cortisol (C_O) occurred in spring and then it gradually decreased until winter, with significant difference ($P < 0.05$). C_O was highly correlated with the variables A_T ($r^2 = 0.61$), R_U ($r^2 = 0.86$), RHL ($r^2 = 0.93$) and R_T ($r^2 = 0.61$).

Spring was the season of minor averages for C_T, H_L, H_D and N_D; however, only N_D was not significantly different between the four seasons (Fig. 3). The Brahman bulls showed larger C_T, H_L and H_D in winter, and this was significantly different to the other seasons.

Variables located far from zero point concentrate most of the total variation and are the most important for explaining the total variance of the data (Fig. 4). In the Brahman bulls population, variables that showed a great association with the first components contributed most to the total variation of the data, and the four physiological responses, hormonal examinations and hair traits were shown in order of importance for each season: (A) spring (R_R, S_R, T_4 and R_T); (B) summer (C_O, T_3, R_T and C_T); (C) autumn (N_D, R_T, R_R and S_R); (D) winter (N_D, R_R, T_3 and T_4).

The bi-dimensional plot for discriminant canonical analysis of the population studied in the four seasons based on all variables are shown in Fig. 5. The adaptive mechanisms were partially similar in the summer and autumn seasons, while spring and winter occupied independent and well-defined places in the quadrant. Table 2 contains classifications of the animals by canonical discriminant analysis according to the studied variables. No group of variables concentrated all the animals in the correct season according to the physiological responses, hormonal examinations and hair characteristics (*1*), physiological responses and hormonal examinations (*2*) or hair characteristics (*3*). The highest values were 61 animals in winter, 53 animals in spring, 46 animals in autumn and 37 animals in summer using physiological and hormonal responses and hair characteristic traits. When using only the physiological and hormonal responses, the highest values were 50 animals in autumn, 38 animals in winter and 37 animals in spring. For the hair characteristics, the highest values were 52 animals in winter and 51 animals in spring. Broadly speaking, the physiological and hormonal responses of Brahman bulls in summer resembled their responses in autumn.

The logistic regression (Fig. 6) was significant ($P > 0.001$) for all physiological responses and hormonal concentrations in Brahman bulls. However, R_R and S_R presented greater accentuation in their descending lines, showing that these variables change greatly according to the season. There was also a slight inverse relationship between T_3 and T_4 during the seasons.

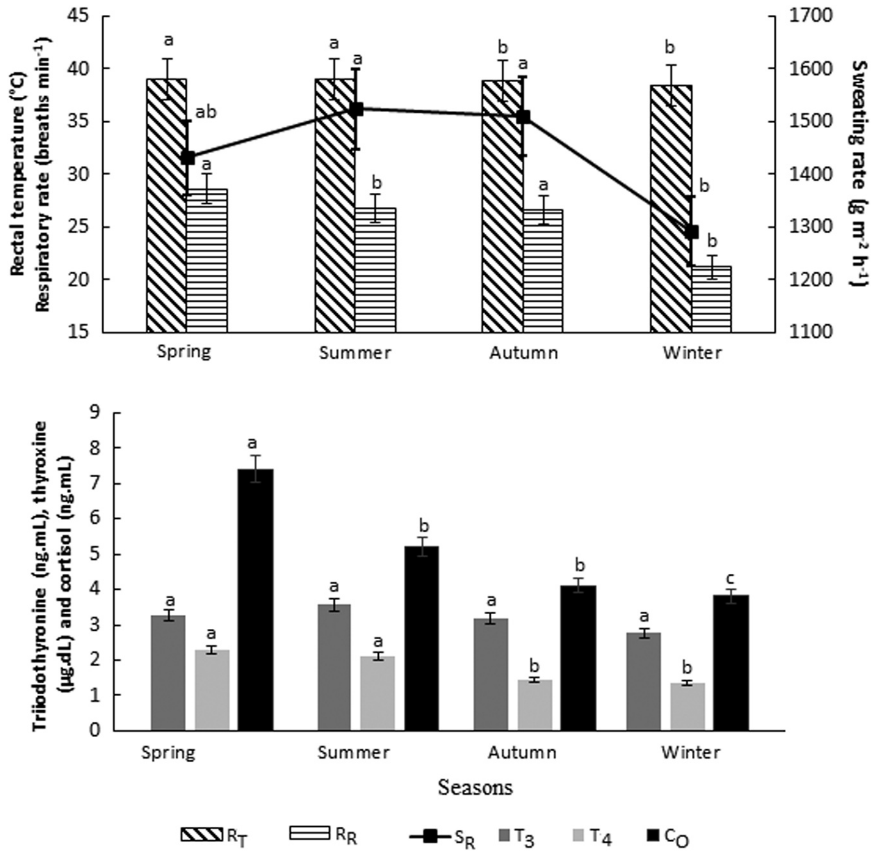

Fig. 2. Physiological responses and hormonal examinations of Brazilian Brahman bulls in Cerrado biome during different seasons

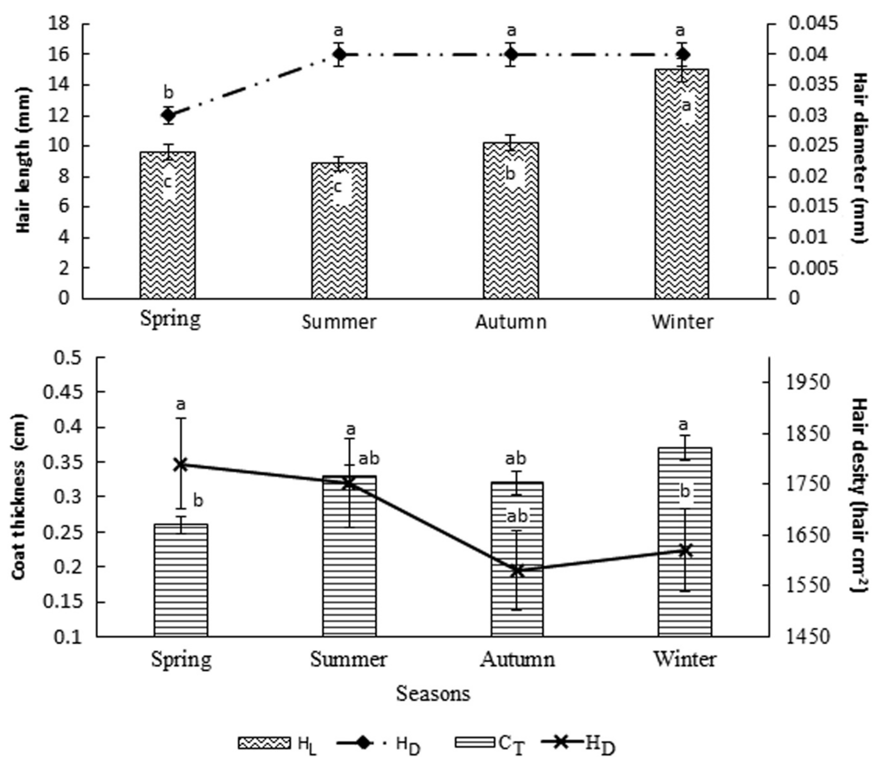

Fig. 3. Hair examinations of Brazilian Brahman bulls in Cerrado biome during different seasons

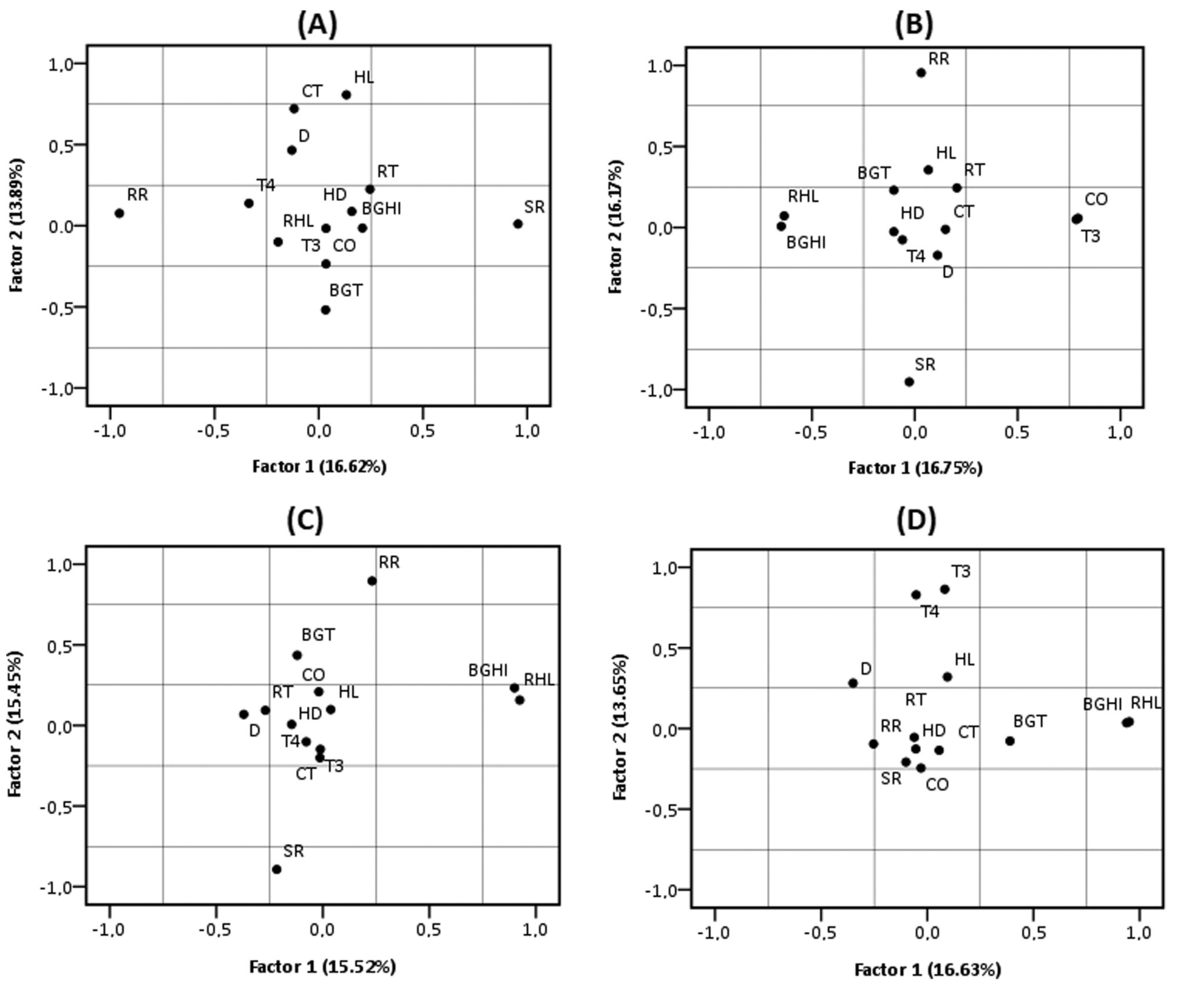

Fig. 4. Bi-dimensional plot of the studied variables in the Brazilian Brahman bulls in Cerrado biome during different seasons. (A) Spring, (B) Summer, (C) Autumn and (D) Winter. R_R, respiratory rate; R_T, rectal temperature; S_R, sweating rate; T_3, triiodothyronine; T_4, thyroxine; C_O, cortisol; C_T, coat thickness; H_L, hair length; H_D, hair diameter; N_D, hair density

4. Discussion

The present investigation is the first to describe the adaptive responses of Brahman bulls, based on physiological, hormonal and hair characteristics according to season using a multivariate approach, specifically canonical analysis. Empirically, it is expected that some periods of the year will be more stressful for animals; however, phenotypic plasticity allows them to overcome these moments. The associated effects of high A_T, R_U and solar radiation can result in a more stressful environment, so in this period the animals must receive special attention to cope with the thermal stress (Katiyatiya et al., 2017; Srikanth et al., 2017; Silva et al., 2017). McManus et al. (2011) states that animal production is not related to a single trait or characteristic, but includes adaptation to the environment, disease and parasite resistance, nutritional parameters, production and body indices as well as reproductive traits, among others.

The four seasons present in this study were partially defined for the Brazilian Cerrado biome. Its meteorological characteristics made the effect used in the present study a promising means to evaluate the adaptive responses of the Brahman bulls. Although most of the Brazilian regions do not present four well-defined seasons, especially those that are located in the North and Northeast, different profiles can be observed between the months that comprised the four seasons. September and November, which corresponded to spring, had lower A_T and R_U compared to other months, and it had a W_S range of 6.7–3.2 m s^{-2}. January and February, corresponding to summer, and March and April, corresponding to autumn, were closest in terms of meteorological characteristics. Both had higher A_T associated with a high R_H and low W_S. In June, the new cycle begins, with A_T beginning to decrease along with H_R and W_S.

Current research seeks to identify the main characteristics of a breed, allowing adequate management for each type of animal, as found in the work of Charoensook et al. (2012), who reported breed-specific thermophysiological responses to HS.

According to Balamurugan et al. (2017), beef cattle are particularly vulnerable not only to extreme environmental conditions, but also rapid changes in these conditions. Increased W_S increases convective heat loss by increasing evaporative exchange between the body and the environment, which ultimately reduces the R_T (Correa et al., 2013). In concordance with Cena and Monteith (1975), who found that heat transfer attributed to conduction throughout the coat is not as significant as free convection and radiation exchange between the hairs, which are most responsible for heat transfer through the coat when Ws is low. However, this depends on external or internal factors linked to the animal and the environment.

The animals that participated in the research were at a stage

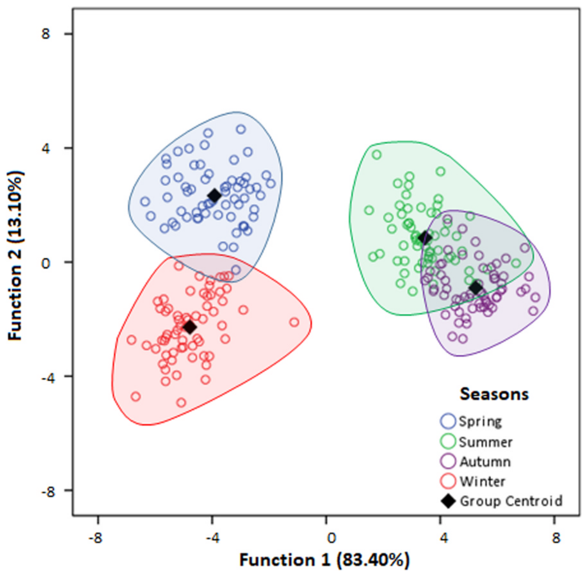

Fig. 5. Bi-dimensional plot for discriminant canonical analysis for all variables of Brazilian Brahman bulls in the different seasons

Table 2
Percentage of animals classified in each group according to the studied seasons

Seasons	Spring	Summer	Autumn	Winter
1. *All variables*				
Spring	53 (84.1%)	2 (3.2%)	7 (11.1%)	1 (1.6%)
Summer	5 (7.9%)	37 (58.7%)	19 (30.2%)	2 (3.2%)
Autumn	6 (9.5%)	9 (14.3%)	46 (73,0%)	2 (3.2%)
Winter	0 (0%)	0 (0%)	2 (3.2%)	61 (96.8%)
2. *Physiological responses and hormonal concentrations*				
Spring	37 (58.7%)	5 (7.9%)	20 (31.7%)	1 (1.6%)
Summer	8 (12.7%)	28 (44.4%)	23 (36.5%)	4 (6.3%)
Autumn	5 (7.9%)	5 (7.9%)	50 (79.4%)	3 (4.8%)
Winter	2 (3.9%)	4 (6.3%)	19 (30.2%)	38 (60.3%)
3. *Hair examinations*				
Spring	51 (81.0%)	3 (4.8%)	5 (7.9%)	4 (6.3%)
Summer	17 (27.0%)	23 (36.5%)	21 (33.3%)	2 (3.2%)
Autumn	16 (25.4%)	11 (17.5%)	31(49.2%)	5 (7.9%)
Winter	5 (7.9%)	3 (4.8)	3 (4.8%)	52 (82.5%)

Note: The sum between columns correspond to the total of animals; 63 animals correspond to 100% classification in relation each season.

considered important in the beef industry, and it is understood that as they got older, bigger and heavier, associated with being in different seasons of the year, they would present modifications in their physiological responses of thermoregulation conditions and changes in their hair coat. According to Silva (2000), the higher the body mass of the animal, the lower proportion of surface contact available for heat loss; however, an increase in cattle weight has been attributed to body growth (Alfredo et al., 2008).

Associated with behavioral characteristics, the physiological processes of thermoregulation are the first to be activated in different environments, according to Castanheira et al. (2010); physiological variables are excellent indicators of health status in ruminants (Johnson et al., 2012). Brahman bulls maintained high phenotypic plasticity for these characteristics, directly modifying R_R, R_T and S_R, and similar results were shown by Quesada et al. (2001), Castanheira et al. (2010) and McManus et al. (2010). A change in R_R was observed, which is considered a very unstable variable to promote responses to different stimuli (Quesada et al., 2001). According to Castanheira et al. (2010), physiological variables are excellent indicators of health status in ruminants, but they must be properly interpreted, as they may be influenced by species, age, exercise, and excitement.

Morphological traits are important, as they directly affect heat exchange mechanisms such as cutaneous convection, radiation and loss of latent heat to the environment by cutaneous evaporation (Maia et al., 2003). The hair characteristics are of great importance for the adaptation of the animals, interfering in the ability of the animals to dissipate heat and control metabolizable energy necessary for body maintenance (Holmes, 1981; Stone et al., 1992; Façanha et al., 2015). It is recommended that bovines raised under an extensive regime have well-settled hairs to favour the protection of the epidermis and the loss of heat, reducing the amount of air trapped inside the coat (Silva, 2000). As a consequence of natural selection, bovines kept in hot environments often present a highly pigmented epidermis, in combination with white or light skin (Bianchini et al., 2006), as in the Brahman breed. According to Silva et al. (2003), it is a way of protecting the deep tissues from the dangerous action of shortwave ultraviolet radiation (< 300 nm), which easily crosses the fine layer of the fur of these animals.

Changes in C_T may hamper the release of latent heat from the body to use compensatory mechanisms, which lead to energy generation, an unfavorable factor in animal production (Stone et al., 1992; McManus et al., 2011). The method used in the present study evaluated C_T, which means a more detailed analysis of this point cannot be made. Research shows that the C_T was associated with resistance to HS, but that they modify their function when the skin is thin (Yeates, 1954) or thick (Finch et al., 1984).

In the present study, Brahman bulls presented minor values of C_T, as in the work of Façanha et al. (2015), which was associated with a lower N_D. Bertipaglia et al. (2008) and Façanha et al. (2015) found similar values for C_T and H_L, and classified the study animals as having lower C_T and moderately long H_L. According to Yeates (1954), H_L is an important trait linked to animal adaptation in the tropics, where longer hair is linked to animals more affected by HS in the different seasons, as in the present study, in which the animals have very long hairs in the winter season.

Similarly, Marai and Haeeb (2010) indicated that H_L is also highly correlated to the number of apocrine glands. A higher number of hairs mean the animals have a higher number of sweat glands and better adaptation to hot climates (McManus et al., 2011). The importance of S_R on the amount of heat lost by cattle is highlighted by several studies (Schleger and Turner, 1965) and is subject to considerable variation within the individual's responses. Moreover, there are differences between breeds and groups of animals depending on the environment in which they can be found (McManus et al., 2009). McLean (1963) showed that European cattle (*B. taurus*) under HS dissipated about 75% of latent heat through sweating and was also the case for Zebu cattle (*B. indicus*).

From the discriminant analysis, it can be verified that none of the groupings of variables was enough to characterize the Brahman bulls for each season. Many of the animals that were supposed to fit in the summer were present in the autumn and vice versa. The association between all variables, physiological responses and hair characteristics, was shown to be the best way to classify the animals. This pattern is a reflection of the inter-relationships between physiological responses and hair characteristics.

5. Conclusion

We concluded that Brazilian Brahman bulls exhibited physiological responses, hormonal and morphological characteristics that promote dynamic adaptation according to season in Cerrado biome conditions.

For that reason, this breed can be indicated for meat production in an extensive system. However, special attention must be paid to heat stress management during the hottest and humid months, in this case January to June, corresponding to the summer and autumn seasons.

Multivariate analysis was effective in separating Brahman bulls using physiological responses, hormonal examinations and hair characteristics, and logistic regression showed a marked effect on S_R and a

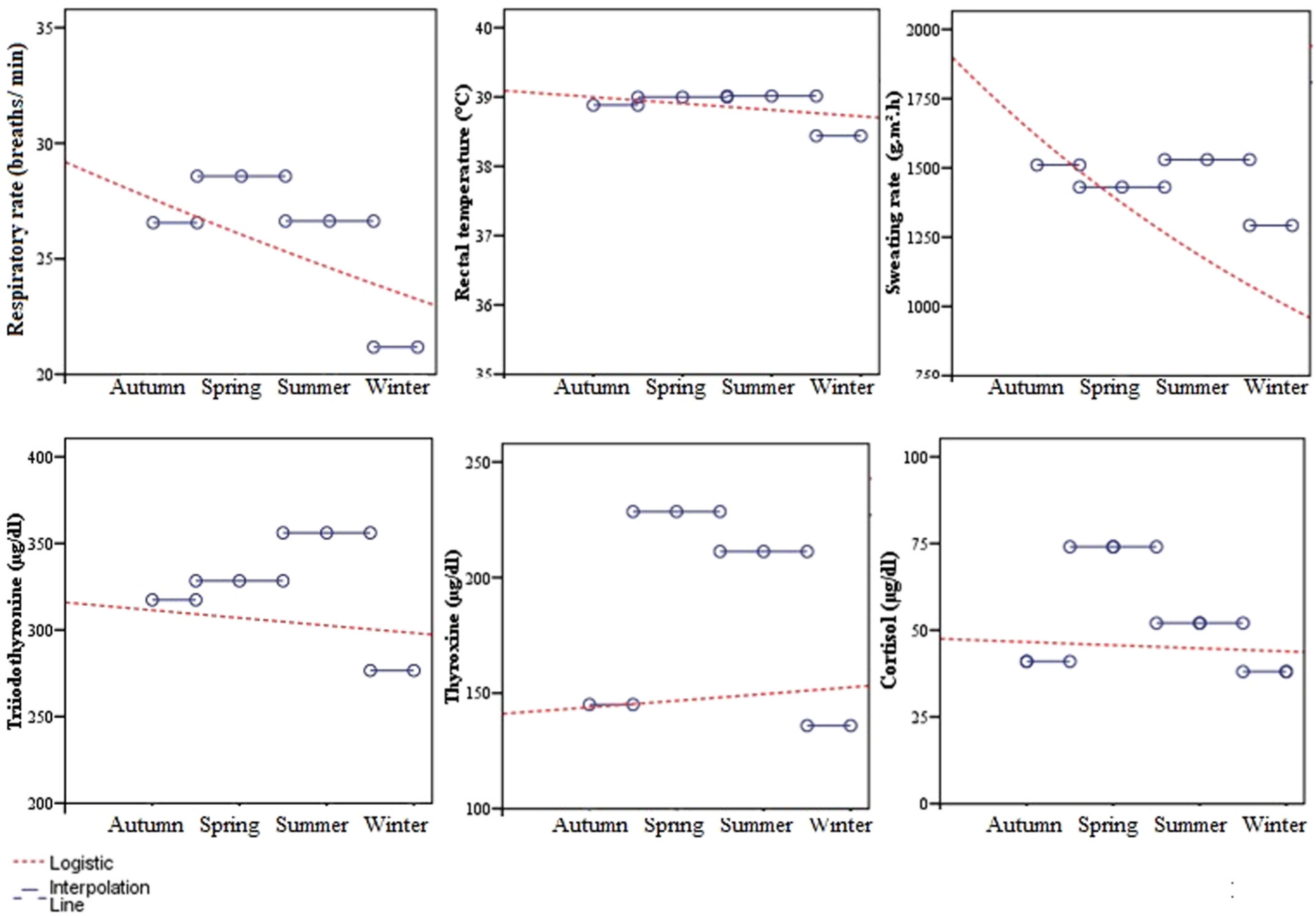

Fig. 6. Logistic regression of the physiological responses and hormonal examinations of Brazilian Brahman bulls in Cerrado biome during different seasons

small inverse relationship between the thyroid hormones (T_3 and T_4) during the seasons.

Authorship statement

The idea for this paper was conceived by D. Façanha and J. Ferreira. The experiments were designed by J. Ferreira. The experiments were conducted by D. Façanha, J. Leite, W. Costa and A. Vasconcelos. The data were analyzed by J. Ferreira, R. Silveira, J. de Sousa and L. Asensio. The paper was written by D. Façanha and J. Ferreira.

Acknowledgement

The authors acknowledge the Uberbrahman Group, specially Dr Thiago Camargo and Dr Aldo Valente, that supported the present study.

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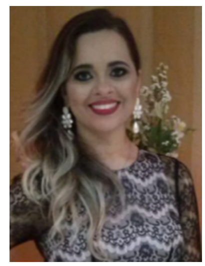

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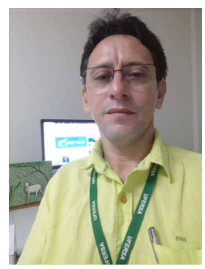

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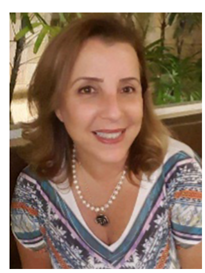

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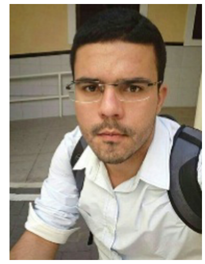

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